ith the Author's
Compliments

EXPERIMENTS
ON THE
OXIDATION OF IRON,
WITH APPENDICES.

GALVANIZED IRON FOR ARMOUR-PLATED SHIPS;
PRESERVATION OF IRON-PLATED AND OTHER SHIPS;
THE ACTION OF SEA WATER ON METALS AND ALLOYS;
THE ACTION OF WATER UPON LEAD.

BY

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EXPERIMENTS

ON THE

OXIDATION OF IRON.

Some two years since, Sir Charles Fox inquired of me if I could give him the exact composition of iron-rust, viz., the oxidation found on the surface of metallic iron. I replied that it was admitted by chemists to be the hydrate of the sesquioxide of iron, containing a trace of ammonia; to this he answered that he had read several books on the subject in which the statements referring to it differed, and, from recent observations he had made, he doubted the correctness of the acknowledged composition of rust. He further stated that, if he took a bar of rusted wrought iron and put it into violent vibrations by applying at one end the fall of a hammer, scales would be separated which did not appear to him to be the substance I had described.

This conversation induced me to commence a series of experiments which I shall now detail.

I first carefully analyzed some specimens of iron-rust which were procured, as far as possible, from any source of contamination. Thus, one of these samples was supplied to me by Sir Charles Fox as taken from the outside of the Conway Bridge, the other secured by myself at Llangollen, North Wales.

These specimens gave the following results when submitted to analysis :—

	Conway Bridge.	Llangollen.
Sesquioxide of iron..............	92·900	93·094
Protoxide of iron..................	6·067	5·810
Carbonate of iron	0·617	0·605
Carbonate of lime	0·295	0·295
Silica	0·121	0·196
Ammonia	trace	trace
	100·000	100·000

These results clearly show the correctness of Sir Charles Fox's statements that the composition of the rust of iron is far more complicated than it is stated in our text-books. Therefore, the question may be asked, is the oxidation of iron due to the direct action of the atmosphere, or to the decomposition of its aqueous vapour? or, does the very small quantity of carbonic acid which it contains determine or intensify the oxidation of metallic iron? To reply to these queries I have made a long series of experiments extending over two years, which I hope will tend to throw some light on this very important question ; and, although it appeared to me an easy matter to solve, still I have had many difficulties to overcome, which will be described as they occurred in the course of my investigations.

The first series of experiments consisted in placing crinoline and steel wires, very carefully cleaned, in tubes containing pure, dry, or moist oxygen ; and in another series of tubes, containing the same gases, was added 1 per cent. of carbonic acid or a trace of ammonia.

Before describing the facts observed, I must state that the oxygen was prepared from pure chlorate of potash, mixed with a little binoxide of manganese, and the gas obtained passed through several feet of U-tubes filled with glass moistened with sulphuric acid and caustic potash. The carbonic acid was purified by washing it with water and passing it through U-tubes containing sulphuric acid. The ammonia was purified by first passing it through a saturated solution of ammonia and then over caustic lime. These purified gases were then introduced into tubes having 1 centim. diameter, and 30 centims. in length, which had been previously filled with dry mercury, and containing an iron blade, to the bottom of which had been fixed a small mass of gutta percha, so as to isolate the iron from the mercury, and prevent galvanic currents.

The results of the above experiments were so unsatisfactory that I was led to infer that I had overlooked some source of error; and it was so; small globules of mercury, having adhered to the perfectly polished surfaces of the iron, had become centres of galvanic action—determining the oxidation on the blades, and thus rendering the series of experiments discordant.

To overcome this source of error, cleaned blades of steel and iron, having a gutta percha mass at one end, were introduced into similar tubes to those employed in the previous experiments, and were placed over a mercury-trough; the atmospheric air was displaced by a current of pure oxygen conducted to the top of the experimental tube, and it was then easy to introduce into them traces of moisture, carbonic acid, and ammonia. After a period of four months the blades of iron so exposed gave the following results:—

Dry oxygen	No oxidation.
Damp oxygen	In three experiments; only one blade slightly oxidized.
Dry carbonic acid	No oxidation.
Damp carbonic acid	Slight appearance of a white precipitate on the surface of the iron—found to be carbonate of iron; two only out of six experiments did not give this result.

Dry carbonic acid and oxygen	No oxidation.
Damp oxygen and carbonic acid ...	Oxidation most rapid, a few hours being sufficient; the blade assumed a dark green colour, which then turned brown-ochre.
Dry oxygen and ammonia	No oxidation.
Damp oxygen and ammonia	No oxidation.

The above results prove that, under the conditions described, pure and dry oxygen does not determine the oxidation of iron; that moist oxygen has only a feeble action; dry or moist pure carbonic acid has no action, but that oxygen containing traces of carbonic acid acts most rapidly on iron, giving rise to protoxide of iron, then to carbonate of the same oxide, and lastly to a mixture of saline oxide and hydrate of sesquioxide.

As these facts tend to show that carbonic acid is the agent which determines the oxidation of iron, I am justified in assuming that it is the presence of carbonic acid in the atmosphere, and not its oxygen or aqueous vapour, which determines the oxidation of iron in common air.* Although this statement may be objected to at first sight, on the ground of the small amount of carbonic-acid gas existing in the atmosphere, still we must bear in mind that a piece of iron, when exposed to its influences, comes in contact with large quantities of carbonic acid during twenty-four hours.

These results appeared so interesting that I decided to institute several series of experiments.

First Series.—Perfectly cleaned blades of iron placed in bottles filled with ordinary Manchester water were rapidly covered with rust, whilst similar blades, placed in the same water previously deprived of air and carbonic acid by boiling, remained free from rust for a period of four weeks; thus proving that oxygen and carbonic acid are necessary for the production of oxide of iron in presence of water.

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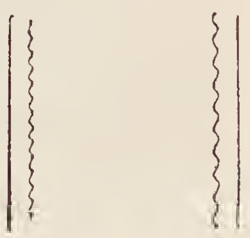
* These results prove the statement of Bonsdorff (see Gmelin, vol. v p. 185), that carbonic acid has no action on iron, is incorrect.

Second Series.—Into bottles filled with some pure distilled water (which had been boiled and then allowed to cool in corked flasks) blades of iron were introduced, and a part of the water in the bottles was displaced by common air, pure oxygen, or carbonic-acid gas; but the results were unsatisfactory. I therefore decided to keep the upper part of the blade dry; to effect this, cleaned blades of crinoline-wire were introduced into bottles containing pure oxygen, and then boiled, and cooled distilled water was introduced by means of an aspirator until only half the blades were immersed in the water. By this method I was enabled to ascertain the comparative degree of oxidation of that part of the blade dipping in the water, and the results observed were as follows:—

The section of the blades out of the water remained bright for several days, whilst that in the water became attacked in about six or twelve hours; and the deposit increased so quickly that, after two or three days, the blade was entirely covered with an ochre deposit of the hydrated sesquioxide of iron. This rapid oxidation of iron under these circumstances appeared to me to be entirely due to a galvanic current; for the oxide was deposited in two separate columns, which left the outside edges of the blade perfectly bright as well as the centre of it, each separate column apparently representing the poles of a battery. In fact, the production of this precipitate was so rapid that, after a short time, a considerable amount was found as a deposit in the bottle.



To be certain that the oxidation of the immersed portion of the blade was not due to the fixation of oxygen dissolved in the fluid, but to the decomposition of water through a galvanic current, I examined the gaseous mixtures existing in the upper part of the bottle, and found hydrogen in large quantities, thus proving that the water had been decomposed, its oxygen being fixed by the iron, whilst the hydrogen was liberated.

Action of Oxygen-carbonic Acid on Iron in presence of Water.

To ascertain the influence which carbonic acid exerts on the oxidation of iron, I prepared mixtures of oxygen and carbonic acid in the following proportions :—

25	of oxygen to	75	of carbonic acid.
50	,,	50	,,
75	,,	25	,,
84	,,	16	,,
88	,,	12	,,

Having introduced iron blades and the above gaseous mixtures into bottles, they were inverted over water so that their necks dipped into this fluid ; when half the gaseous mixture had been displaced by aspiration, as in the previous experiments, the following results were obtained, viz., whilst that portion of the blade standing out of the water in the previous experiments remained for weeks unoxidized, in this series the same section of the blade assumed rapidly a dark colour, which became afterwards of a dark brown. This change of colour was no doubt due—first, to the formation of carbonate of the protoxide of iron, mixed with carbon existing in the iron, and then the excess of oxygen in the mixture converted the carbonate into magnetic or saline oxide of iron, with a little sesquioxide of iron. Whilst these phenomena were proceeding with that portion of the blade exposed to the gaseous atmosphere, the one dipping into the aqueous solutions was observed to lose its brilliant and metallic lustre in a few minutes, presenting a black appearance, which became, at the end of three hours, of a dark greenish hue, due to the formation of similar compounds as those above described.

In all these experiments the water became not only turbid after a short time, but on the surface of the same floated a considerable amount of magnetic oxide and carbonate of the protoxide of iron, and which varied in quantity acording to the relative proportions of oxygen and carbonic acid employed. This series of experiments confirms again the previous ones, that carbonic acid is a most active agent in determining the oxidation of iron.*

ACTION OF CARBONIC ACID ON IRON IN PRESENCE OF WATER.

Having studied the action of oxygen and of carbonic acid and oxygen on iron in the presence of water, I was desirous of ascertaining what would be the action of carbonic acid and water. I operated in a similar manner as in the previous experiments, and observed that the blades in the gaseous mixtures had assumed a dark grey appearance; *that* in the liquid was black, the carbon having been rendered perceptible by the iron having been dissolved as carbonate of protoxide of iron, soluble in the excess of the carbonic acid. After a few days, a perfectly white deposit was formed on the edge of the water, which gradually increased and became so abundant that some fell to the bottom of the vessel. Water had been decomposed and hydrogen liberated.

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* The composition of the various deposits above described was not assumed, but was determined by careful analysis.

I again made another experiment which further illustrates that carbonic acid is the real determining agent of the oxidation of iron. Thus:—A blade of steel placed in pure water which had been previously deprived of all gaseous mixtures by long boiling, and then allowed to cool; the metal remained bright for several days, and, when any signs of oxidation appeared, it was only on a few parts of the blade. The careful examination of this fact led me to infer that the limited action which had taken place might be attributed to traces of impurity in the iron; and this view was supported by the previous observations described on the influence which minute globules of mercury exert on the oxidation of iron, as well as the known influence which a few thousandths of antimony, platinum, tungsten, sulphur, phosphorus, &c., impart to iron; and, again, the facts I published a few years ago, that, by covering the one-hundredth part of a blade of iron with zinc, the whole of the blade is prevented from rusting when plunged in soft or sea water; whilst platinum, under the same circumstances, promotes, in a marked degree, the oxidation of iron. Therefore, if a minute quantity of a substance modifies the properties of iron so as to facilitate or retard its oxidation, we may, I think, fairly assume that any impurity in the purest steel (watch-springs) may give rise to the few specks of oxide which were observed in the steel placed in boiled distilled water.

Whilst I was engaged in the above experiments, it occurred to me that it might be useful to make a series with the view of throwing light, if possible, on a fact stated by Berzelius, and well known to alkali and soap-manufacturers, viz., that caustic alkalies have the property, even when dilute, of preventing the oxidation of iron.

Do the alkalies possess the curious property of rendering the iron "passive," or, as Berzelius has supposed, is the iron in a negative electrical condition? This is a very difficult question to solve. From many observations I have made, I am led to believe that the iron is in a passive state; and this opinion is based, not only on the known data, that a blade of iron is not attacked by a strong nitric acid, and that we have no electrical current if one fluid and one metal are brought in contact, whilst if two fluids and a metal, or two metals and one fluid are employed, a galvanic current is generated. My experiments show that not only caustic alkalies possess this peculiar property, but also their carbonates and bicarbonates; and I hope that the following experiments will throw some light on this point. A blade of polished iron was dipped into a solution of caustic soda, and at each end of the blade was attached a wire communicating with a galvano-multiplicator, and no galvanic current was generated; and, again, when blades of perfectly polished hoop-iron were placed in bottles half-filled with solutions of caustic alkali, carbonates, and bicarbonates containing from 1 to 5 per cent. of these compounds, and only a part of each blade was immersed in the solution, the other part being exposed to atmospheric air enclosed in the stoppered bottles, the results were that, after three months, neither that portion of the blade dipping in the liquid nor that in the atmosphere was in any way rusted in the solutions containing 5 per cent. of alkali; and, in the experiments with 1 to 2½ per cent., only parts of the blades out of the water were slightly oxidized.

I was much surprised to find that the carbonates and bicarbonates of the alkalies acted in the same manner as their hydrates in preventing the oxidation of iron not only on that part of the blade immersed in the solutions but also on that which was exposed to a damp atmosphere of common air. Previously to obtaining these results, I was inclined to believe that caustic alkalies prevented the oxidation of iron by absorbing the carbonic acid of the atmosphere; but, as carbonates and even bicarbonates act in a similar manner, it is evident that this view of the action was erroneous.

The results above stated not coinciding with those obtained by Payen, and given in Gmelin (vol. v. p. 185), I repeated his experiments, and found that the portions of the blades of iron immersed in dilute alkaline solutions as described by him are preserved from oxidation, but that the portion out of the liquor becomes covered with oxide, which increases in inverse ratio to the strength of the solution, and that when the proportion of 1 part of the alkali to 2000 parts of water is reached, the oxidation of the iron proceeds rapidly on that part of the blade just above the surface of the water.

This series of experiments confirms the opinion already expressed that the iron exists in a passive condition, and that this condition only attains sufficient power to resist oxidation by atmospheric oxygen when there is 5 per cent. of either hydrate or carbonates of alkalies in solution.

I have repeated also M. Payen's experiments on the preservative action of weak solutions of carbonate of soda, and find that my results do not correspond with his. He states that 1 part of a saturated solution of carbonate when diluted with 54 parts of water will preserve iron from rust, while 1 with 59 will not. I find that the iron rusts in both cases, thereby proving that stronger solutions are necessary to prevent oxidation.

I have made many experiments with the view of discovering the cause of this interesting preservative action which alkaline solutions exert on iron, but have failed.

Knowing the destructive influence which sea-water has on iron, and the serious injury done to iron ships through the action of bilge-water, a series of experiments were made with sea-water to which was added such a quantity of caustic soda or potash or their carbonates that, after the salts of lime and magnesia were decomposed, there still remained in the solutions 1 to 5 per cent. of alkalies or the alkaline carbonates ; and, when iron blades were introduced into such liquids, they gave the same results as when iron had been dipped partially into an alkaline solution of Manchester water. I would propose, in conclusion, that a certain quantity of soda-ash should be introduced from time to time into the bilge-water of iron ships, as by so doing a great saving would be effected, as it would prevent the rapid destruction of such ships.

After reading the above paper, Mr. E. Hunt inquired whether I had made experiments to ascertain if the presence of caustic alkalies or their carbonates when mixed with sugar prevented the marked action of that substance on iron. Considering this a most important question to determine, as iron ships are rapidly destroyed when used for conveying sugar from the colonies to this country, I instituted the following series of experiments :—

Blades of iron were partly immersed in a solution containing 10 per cent. of sugar, and in similar solutions to which had been added 2½ to 5 per cent. of caustic and carbonate of soda ; after a month the same results were obtained with the saccharine as with the aqueous solutions. But as it would be impracticable to use solutions of caustic or carbonated alkalies in the holds of ships laden with sugar, I thought it therefore advisable to try what might be the influence of zinc when attached to iron in preventing its oxidation, and am glad to say that a piece of zinc covering about the fiftieth part of the blade preserves the iron from rusting in that part of the blade immersed in the sugar-solution. The use, therefore, of plates of zinc fixed on the sides of an iron vessel, or, perhaps better, the employment of galvanized iron plates in the construction of ships, deserves the attention of shipowners.

APPENDIX.

Galvanized Iron for Armour-plated Ships.

During the early part of the year 1862, I had been engaged for some time in ascertaining the chemical composition of various woods employed and susceptible of being employed in the navy. At that time, having visited one of the dock-yards, I found that, while the armour-plates were fixed against a layer of teak, the ribs of the ship were of oak, and that the iron bolts which were to fasten the plates were to pass through the oak ribs. It occurred to me that the inconvenience which would probably result from the action of the oak upon the iron might be obviated by substituting galvanized iron bolts for those then used, and I therefore instituted a series of experiments, the result of which I have great pleasure in again publishing.

The first series of experiments consisted in driving through large pieces of oak bolts and screws of unprepared iron, and of galvanized iron, prepared by my friends, Messrs. Richard Johnson and Brother, of Dale Street, Manchester, which were then immersed in soft and sea water for three months. The results clearly showed, firstly, that the friction did not remove the zinc from the galvanized iron; secondly, that the oak and galvanized bolts were unchanged, whilst the unprepared iron bolts were much rusted and the pieces of oak had become quite black, owing to the formation of tannate and gallate of proxide of iron. During the experiments the waters were changed every week, those containing the galvanized iron appearing unaltered, whilst, in the case of the unprepared iron, they had a dark blue-black appearance, owing to the formation of the above-named salts.

In order to ascertain the comparative action of soft and salt water upon iron and galvanized iron when in contact with oak under identical circumstances, I made the following series of experiments.

Plates of galvanized iron, having 18 inches of surface, lost during the three months the following weights :—

	SOFT WATER.	SEA WATER.
Plate No. 1	0·10 grains	...
„ „ 2	0·11 „	...
„ „ 3	...	0·095 grains.
„ „ 4	...	0.090 „

Similar plates of iron lost during the same time—

	SOFT WATER.	SEA WATER.
Plate No. 1	1·23 grains	...
„ „ 2	1·52 „	...
„ „ 3	...	2·40 grains.
„ „ 4	...	2·38 „

There can therefore be no doubt that galvanized iron offers great advantages, the action of water upon it being less than a tenth of the same action on unprepared iron ; and further, as iron, when galvanized, is in the most favourable electrical condition to resist the action of oxygen, being in an electro-negative condition, it follows that, in all probability, the use of galvanized iron would be very advantageous in armour-plated and other iron ships.

PRESERVATION OF IRON-PLATED AND OTHER SHIPS.

The following letter, addressed by myself to the Secretary of the Society of Arts, London, appeared in the pages of the journal of that society in the issue of the 14th of August, 1863:—

"Sir,—I have read with much pleasure the interesting paper which has appeared in your journal respecting the patent of Mr. Jean Pierre Jouvin for preserving iron-plated and other vessels and metallic articles from oxidation, and preserving ships' bottoms from fouling.

"My object in addressing these few lines to you is not to discuss this important invention, but to lay before the members of the Society a few facts which I have observed during the last few years, in the course of some researches which Mr. Richard Johnson and I have made on this most interesting subject.

"In the year 1858 Mr. Johnson and I took plates of iron, and covered one surface with one-twentieth, one-fortieth, one-eightieth, and one-hundredth of its extent of zinc plate, which we tied close to the iron plates, and then immersed them in soft and sea water. We examined these plates at the end of one, two, and three months, and, finding that the zinc had exercised a very remarkable preservative effect upon the iron, we brought the matter under the notice of Mr. Robinson, shipbuilder, at Newcastle, who promised to institute a series of experiments, in connection with his iron ships, to ascertain whether the results obtained in my laboratory would be confirmed on a practical scale, but this gentleman soon after fell ill and ultimately died. In the meantime, it occurred to us that the most practical mode of applying zinc for the preservation of iron ships would be to use galvanized iron, and we therefore instituted a series of experiments to ascertain the extent to which protection would be thus afforded.

"Plates of iron of three inches square were attached with great care to pieces of oak of the same surface and immersed in soft and sea water, and the following were the results observed after two months' immersion, viz., from January 3rd to March 5th, 1862:—

		Loss by corrosion, in grms.
Pieces of wood and iron	in distilled water	1·230 1·230
	in salt water	2·400 2·380
Pieces of wood and galvanized iron	in distilled water	0·100 0·125
	in salt water	0·095 0·090

We were anxious to know whether a prolongation of the experiment would continue to show the same comparison, and we therefore again immersed the plates in distilled and sea water until May, 1863, when the iron plates were again removed from the pieces of oak, carefully washed and dried, and weighed—

Pieces of wood and iron	in distilled water	1·700 1·550
	in salt water	4·320 4·280
Pieces of wood and galvanized iron	in distilled water	0·500 0·830
	in salt water	0·780 1·220

"These results leave no doubt of the great protective power exercised by zinc against the corrosive action of water, and especially of sea water, upon iron plates. I therefore think that all iron used in shipbuilding should be galvanized, and, as this operation is now performed with such great facility and so little expense, I cannot see any commercial objection to its general adoption.

"There is a further argument in favour of this course in the fact that it is not the loss of the iron only that is in question, important as that is, but there is also the wood, which, especially in the case of oak, is rapidly deteriorated by the presence of oxide of iron, upon which the gallic and tannic acids of oak exercise a powerful action, and thus cause the wood to enter into a state of rapid decay, or emaracausis, well known to shipbuilders.

"Mr. Johnson and I also deemed it advisable to ascertain whether the zinc was liable to be removed from the surface of iron by intense friction, and to decide this point we made the following experiments :—

"Large bolts, one foot long, and half an inch in diameter, were driven into solid blocks of oak by a sledge-hammer, the blocks were then opened and the bolts found to be not in the slightest degree uncoated. Another series of experiments was made, consisting of driving screws of the same diameter as the bolts into solid blocks of oak, and the same satisfactory results were obtained.—I am, &c.,

"F. CRACE CALVERT.

"Manchester Royal Institution, August 12th, 1863."

ON THE ACTION OF SEA WATER UPON CERTAIN METALS AND ALLOYS.

(From the Journal of the Society of Arts, April 21, 1865.*)*

We were induced to examine the action exerted by sea water in consequence of the rapid changes which have taken place of late years in naval architecture, and especially in the substitution of metals and alloys for wood, and because one of us is largely engaged in the manufacture of wire for submarine and other telegraphs, and, when spun into ropes, for ships' rigging.

To carry out the above views we took 20 square centimetres of each metal, which we cleaned with great care and attention, in order that the action of the sea water might have its full effect; then two plates of each metal were placed in separate glass vessels, and immersed in equal volumes of sea water. After one month the plates were taken out, and any compounds that had adhered to the surface carefully removed; the plates were then dried and re-weighed, and the loss estimated. To render our results of more practical value, we have calculated the action of 100 litres of sea water upon one square metre of each metal, and the following are the amounts of metal dissolved :—

Steel	29·16
Iron	27·37
Copper (best selected)	12·96
Copper (rough cake)	13·85
Zinc	5·66
Galvanized Iron (Johnson's process)	1·12
Block Tin	1·45
Stream Tin	1·45
Lead (Virgin)	Trace
„ (Common)	Trace

These results lead to the following conclusions :—

1. That steel is the metal which suffers most from the action of sea water.

2. That iron is most materially preserved from the action of sea water when coated with zinc, and, therefore, not only should iron exposed to the action of sea water be galvanized whenever this is practicable, but, in our opinion, it would amply repay shipbuilders to use galvanized iron as a substitute for that metal itself.

The above facts perfectly confirm those which we have already published in our paper, "On Galvanized Iron for Armour-plated Ships," in which it was shown that when iron was in contact with oak they mutually acted upon each other, producing a rapid destruction of the two materials, whilst little or no action took place between galvanized iron and the wood.

3. The extraordinary resistance, which lead offers to the action of sea water, naturally suggests its use as a preservative to iron vessels against the destructive action of that element ; and, although we are aware that pure lead is too soft to withstand the wear and tear which ships' bottoms

are subjected to, still we think that an alloy of lead could be produced which would meet the requirements of shipbuilders.

Feeling that experiments made with a limited amount of sea water might not be a fair criterion of the action of the ocean upon metals, we repeated our experiments upon plates of 40 centimetres square, which were immersed for one month in the sea on the western coast (Fleetwood), taking the precaution that they should be constantly beneath the surface of the water, and suspended by flax rope attached to a wooden structure, to prevent any galvanic action taking place between the plates and the structure to which they were attached.

The following are the amounts of metals dissolved :—

	Grammes.
Steel	105·31
Iron	99·30
Copper (best selected)	29·72
Zinc	34·34
Galvanized Iron (Johnson's process)	14·42
Lead (Virgin)	25·69
„ (common)	25·85

The foregoing figures suggest the following remarks :—

That the action has been much more intense, in this instance, than when the metals were placed in a limited amount of water at the laboratory. These results are due probably to several causes acting at the same time, viz. :— that the metal was exposed to the constantly renewing surface of an active agent ; and that there was also a considerable friction exerted on the surface of the plate by the constant motion of the water, there being at Fleetwood a powerful tide and rough seas. What substantiates this opinion is that the lead plates undoubtedly lost the greater part of the weight, not by the solvent action of the sea water, but from particles of lead detached from them, in consequence of their coming in contact with sand and the wooden supports to which they were attached; but, this cause of destruction having been observed with lead plates, it was afterwards carefully guarded against in the case of all the other metal plates.

We also deem it desirable to examine the action of sea water on various brasses. We therefore immersed for one month plates of various alloys in that fluid, and proceeded to record our results.

ACTION OF 200 LITRES OF SEA WATER UPON ONE SQUARE METRE SURFACE OF THE FOLLOWING BRASSES:

Composition of the Brasses.	Quantity of Metals Dissolved.			
	IRON.	COPPER.	ZINC.	TOTAL.
Pure Copper ...... 50 Pure Zinc 50 100	......	1·110	10·537	11·647
Commercial Brass— Copper .... 66· Zinc .... 32·5 Iron and Lead 1·5 100	0·579	3·667	3·324	7·570
Muntz Metal (Sheet)— Copper .... 70· Zinc .... 29·2 Iron and Lead 0·8 100·0	0·438	4·226	2·721	7·385
Muntz Metal (Bars): Copper .... 62 Zinc .... 37 Lead and Iron 1 100·0	0·501	2·697	3·493	6·691
Prepared Brass— Copper .... 50 Zinc .... 48 Tin 2 100	TIN. 0·365	7·04	3·477	10·882

The above table shows how very differently sea water acts upon divers brasses, and the influence exercised upon the copper and the zinc composing them, by the existence in them of a very small proportion of another metal; thus, in pure brass the zinc is most rapidly dissolved (which, *en passant*, is the contrary to what takes place in galvanized iron), while it acts as a preservative to the copper.

Tin, on the other hand, appears to preserve the zinc, but to assist the action of sea water upon the copper.

The great difference between the action of sea water upon pure copper and upon Muntz metal seems to us to be due not only to the fact that copper is alloyed to zinc, but to the small proportion of lead and iron which that alloy contains; and there can be no doubt that shipbuilders derive great benefit by using it for the keels of their vessels.

We were so surprised at the inaction of sea water upon lead that we were induced to compare its action with that of several distinct varieties of water, viz., Manchester Corporation water—well water—distilled water in contact with air—the same deprived of air—and the following are the amounts of metals dissolved by 200 litres of these waters upon one square metre of surface during eight weeks :—

	Grammes.
Manchester Corporation water	2·094
Well water	1·477
Distilled water (with air)	110·003
„ „ (without air)	1·829
Sea water	0·038

These figures require no comment, as they confirm our previous result that sea water has no action on lead, except what arises from friction.

REPORT OF THE SUB-COMMITTEE APPOINTED TO INVESTIGATE THE ACTION OF THE WATER, SUPPLIED BY THE MANCHESTER CORPORATION, UPON LEAD.

To the Committee of the Sanitary Association.

Gentlemen,—We have the pleasure of laying before you the results of a long series of experiments, undertaken with the view of ascertaining whether the water supplied by the Corporation of this city exerts any, and what, action on lead piping.

The Sub-Committee are greatly indebted to Dr. Calvert for the valuable assistance rendered by him in carrying out the experiments at the Laboratory of the Royal Institution.

The lead piping used for the experiments was obtained from two well-known firms, by whom large quantities of the piping used in Manchester have been supplied.

A new pipe of common lead was fitted up, through which the whole of the water used in the Laboratory flowed.

To determine the action of water on this pipe, samples of water were taken each morning after it had remained in the pipe all night, and other samples were taken in the evening after the pipe had been in ordinary use during the day, so as to test the influence of the water upon the lead when merely passing through the pipe, or when only remaining therein during short intervals.

These experiments were continued from July 6th to August 28th, 1859, a period of nearly eight weeks. The quantity of lead found in the water at the commencement was very considerable, gradually diminishing until, at the end of six weeks, no trace could be discovered in the water drawn in the evening; but, after the water had been allowed to remain in contact with the pipe for 12 hours, a considerable quantity of lead was found.

It was deemed advisable to determine, with greater precision, the amount of lead in solution in the water. For this purpose a solution of acetate of lead was used as a standard, containing a thousandth part of a grain of lead in each division of an alkalimeter.

The method of testing employed was as follows :—

A known volume of the water, in which the quantity of lead was to be determined, was acidified with acetic acid and saturated with sulphuretted hydrogen, the result being to give the water a dark tint, varying, in intensity, with the quantity of lead in solution. An equal volume of distilled water was also acidified and saturated with sulphuretted hydrogen. Into this last liquor a quantity of the standard solution of lead was poured, until the saturated distilled water acquired the same depth of tint as the water to be tested. The quantity of standard liquor required was then read off, and the amount of lead per gallon calculated.

By this means the following results were obtained :—

1859. August	30	Morning,	·040	grain per gallon.	Afternoon,	none.
,,	31	,,	·040	,,	,,	,,
September	1	,,	·040	,,	,,	,,
,,	3	,,	·066	,,	,,	,,
,,	4	,,	·040	,,	,,	,,
,,	5	,,	·040	,,	,,	,,
,,	6	,,	·033	,,	,,	,,
,,	7	,,	·033	,,	,,	,,
,,	8	,,	·025	,,	,,	,,
,,	10	,,	·033	,,	,,	,,
,,	11	,,	·020	,,	,,	,,
,,	12	,,	·020	,,	,,	,,
,,	13	,,	·020	,,	,,	,,
,,	14	,,	·020	,,	,,	,,
,,	15	,,	·020	,,	,,	,,
,,	17	,,	·033	,,	,,	,,
,,	18	,,	·020	,,	,,	,,
,,	19	,,	·020	,,	,,	,,
,,	20	,,	·020	,,	,,	,,
,,	21	,,	·033	,,	,,	,,
,,	22	,,	·033	,,	,,	,,
,,	24	,,	·040	,,	,,	,,
,,	25	,,	·033	,,	,,	,,
,,	26	,,	·033	,,	,,	,,

After an interval of about seven months the experiments were again proceeded with. During that period a portion of the supply pipe had been left full of water, with the view of ascertaining what effect would be produced by water remaining stagnant in pipes for a long period, the pipes being again regularly used, as is often the case after a house has been unoccupied and then becomes tenanted.

The stagnant water was drawn off, and fresh water allowed to flow through, for the purpose of cleansing the pipes.

The water was then allowed to remain in the pipes for intervals of 24 hours or more, as may be seen from the following table, and was tested on the morning of each of the days named. We then obtained the following results :—

1860.

Water in pipe	from April	24	to April	25,	contained	·10	gr. per gal.
„	„	25	„	26	„	·10	„
„	„	26	„	27	„	·10	„
„	„	27	„	29	„	·25	„
„	„	29	„	30	„	·10	„
„	„	30	to May	1	„	·10	„
„	May	1	„	2	„	·10	„
„	„	2	„	9	„	·20	„
„	„	9	to June	1	„	·25	„
„	June	1	„	3	„	·10	„
„	„	3	„	4	„	·05	„
„	„	4	„	6	„	·10	„
„	„	6	„	7	„	·05	„
„	„	7	„	8	„	·05	„
„	„	8	„	10	„	·10	„
„	„	10	„	11	„	·05	„
„	„	11	„	13	„	·05	„
„	„	13	„	14	„	·05	„
„	„	14	„	15	„	·05	„
„	„	15	„	17	„	·05	„
„	„	17	„	20	„	·10	„
„	„	20	„	22	„	·10	„

The marked increase of lead, indicated in these results, over those of the previous experiments, tends to show that the action of stagnant water is constant, and so far corrodes the lead that when the pipe is again brought into ordinary use it yields to the water, which passes through a certain portion of the lead compound, which has been produced during the long contact of the water with the pipe.

We also deemed it advisable to ascertain the action of the water on various kinds of supply pipes which have been used or have been proposed to be used for conveying water into dwelling-houses. With this view the following plan was adopted by the Committee :—

Four varieties of half-inch piping, each 18 feet long, and having a tap at each end, were connected with the service pipe, and each coiled and enclosed in a small barrel fastened with a padlock, so as to preclude the possibility of any tampering with the experiments.

The four pipes taken were—

No. 1. Extra tinned lead piping.
,, 2. Ordinary tinned lead piping.
,, 3. Best, or Virgin ,,
,, 4. Common ,,

The following are the results of the experiments on these pipes :—

On the 13th and 14th July, 1860, the quantity of lead found in the water taken from each of these pipes was very large. The experiments were suspended until the 23rd July, when they were repeated. The quantity was then found to be very considerable, but gradually diminished to the 2nd August.

The action of water on these various pipes was so very marked that it was deemed advisable to determine the quantity of lead taken up and held in solution. On the 2nd August a fresh supply of water was introduced into each pipe, which remained there until the 21st of the same month, when samples were drawn for analysis, and the following are the results :—

No. 1.	Extra tinned piping,	·522 gr. per gallon.	
,, 2.	Ordinary ,,	,,	·364 ,,
,, 3.	Best lead	,,	1·369 ,,
,, 4.	Common	,,	·510 ,,

The pipes were cleaned out for another analysis on the 22nd October, and re-filled with fresh water, and samples drawn on the 9th November, which gave the following results:—

No. 1.	Extra tinned piping	·580 gr. per gallon.	
,, 2.	Ordinary ,,	,,	1·019 ,,
,, 3.	Best lead	,,	·981 ,,
,, 4.	Common	,,	1·200 ,,

These results were obtained by precipitation of the lead in the form of sulphuret of lead, and weighing the precipitation in the form of sulphate of lead.

This process of analysis being long and tedious, the standard liquor, before described, was used in the remaining experiments, which were resumed in December, the water remaining in the pipes as before.

	Extra tinned.	Ordinary tinned.	Best lead.	Common lead.
Dec. 18	·10 gr. per gal.	·12 gr. per gal.	·12 gr. per gal.	·12 gr. per gal.
,, 19	·10 ,,	·12 ,,	·12 ,,	·14 ,,
,, 20	·10 ,,	·12 ,,	·12 ,,	·12 ,,
,, 22	·06 ,,	·08 ,,	·08 ,,	·08 ,,

With the view of testing whether the various denominations of piping always yield results similar to those before mentioned, we obtained the same variety of piping from another manufacturer. The following are the results obtained in 1861:—

Water in pipes from	No. 1.	No. 2.	No. 3.	No. 4.
April 24 to April 25	·10	·20	·25	·20
,, 25 ,, 26	·10	·20	·25	·20
,, 26 ,, 27	·15	·20	·20	·20
,, 27 ,, 29	·20	·25	·30	·30
,, 29 ,, 30	·10	·15	·15	·15
,, 30 to May 1	·10	·20	·25	·20
May 1 ,, 9	·20	·40	·45	·60

Water in pipes from	No. 1.	No. 2.	No. 3.	No. 4.
May 9 to May 10	·20	·20	·35	·40
,, 10 ,, 14	·40	·36	·33	·34
,, 14 to June 1	·64	·72	·84	·84
June 1 ,, 3	·32	·48	·32	·48
,, 3 ,, 4	·24	·32	·24	·32
,, 4 ,, 6	·32	·48	·32	·48
,, 6 ,, 7	·24	·32	·24	·32
,, 7 ,, 8	...	·16	·16	·16
,, 8 ,, 10	·16	·16	·16	·16
,, 10 ,, 11	·16	·24	·16	·24
,, 11 ,, 13	·16	·24	·16	·24
,, 13 ,, 14	·16	·16	·16	·16
,, 14 ,, 16	·16	·16	·16	·16
,, 15 ,, 17	·24	·32	·32	·32
,, 17 ,, 20	·32	·32	·32	·32
,, 20 ,, 22	·32	·32	·32	·32

So far as relates to the deleterious effects on the several pipes, the results obtained with this series corroborate, generally, those obtained with the first series, but there are some remarkable variations in the quantity of lead at various times, which appear to indicate a variation in the quality of the water.

In reference to the question under consideration, it is important to know what is the quantity of lead contained in water which has been proved to produce absolute illness requiring medical treatment, and, in five cases recently tested, the following results have been obtained :—viz., 0·1069—0·298—0·123—0·030—and 0·10 grain per gallon respectively.

These quantities, it will be observed, do not exceed those found in the other waters used in the experiments recorded above.

The experiments on which we now report, carried on during a period of more than two years, and in which more than 300 samples of water have been tested, prove—

1st. That the Manchester water does act on lead pipes to a very serious extent.

2nd. That that action continues for a much longer period than is generally supposed.

3rd. That, when the water remains stagnant in the pipes, it not only becomes highly charged with the dangerous poison, but a coating is formed on the inner surface of the pipes, which coating is subsequently detached by the water passing through, and which it impregnates with lead.

4th. That, even after pipes have been used a considerable period, the quantity of lead contained in the water which has remained 24 hours in the pipe is quite as great as in cases where serious effects have been known to ensue to parties using the water.

5th. That the practice of lining lead pipes with tin affords little, and only temporary protection, and is of no practical value.

Bearing in mind that lead is a cumulative poison, and that water containing it may be used for a considerable time, and the foundation be laid for great suffering and physical injury before the symptoms become so marked as to justify a medical man in pronouncing the case to be one of lead-poisoning, the discovery and adoption of pipes for domestic supply, which could not be productive of this evil, are of the greatest moment; especially to our densely populated labour districts.

The first step towards remedying the evil is a thorough conviction of its existence, and of the serious results which may follow from disregarding its importance.

Let the community at large be convinced on these points, and it is most probable that an efficient remedy would be discovered, more especially if the Corporation would offer, to parties engaged in the necessary pursuits, some inducement to produce a pipe economical in cost, easy of application, and on which the water would not act prejudicially.

The subject is one of great importance, and, in the opinion of your Sub-Committee, deserves further and careful investigation.

So long as lead pipes are used, it is of great importance that parties should not use, for dietary purposes, any water which has been allowed to remain in the pipes for even a few hours.

C. E. CAWLEY, Chairman.

October 28th, 1861.

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